The Effect of Aeration on the Composting Process of Distillation Waste from Kaffir Lime Leaves

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Abstract

The extraction process of kaffir lime (Citrus hystrix) leaves is aimed at obtaining its essential oil. However, the residual waste in the form of distilled kaffir lime leaves has not yet been optimally utilised. This residue holds potential as a composting raw material of compost. This study employed naturally occurring mixed-culture microorganism, assessed compost quality based on C/N ratio, temperature changes, yield, visual appearance, and organoleptic characteristics, providing insights into its potential as a sustainable soil amendment. The composting process was conducted using a bin composting method with a chamber volume of 125 cm³. The primary variable investigated was aeration, with two conditions: aerobic and anaerobic. Composting was carried out for a duration of 8 weeks, after which the yield, C/N ratio, organoleptic, and visual characteristics were assessed. The results indicated that anaerobic composting produced a slightly higher yield. In the eighth week, the yield of anaerobic composting was recorded at 2.1%, whereas aerobic composting yielded 1.8%. Both treatments produced compost with C/N ratios that conformed to the Indonesian National Standard (SNI), measured at 15.86 and 16.42 for aerobic and anaerobic processes, respectively.

Keywords: *aeration; composting; kaffir lime leaves; waste.*

1. INTRODUCTION

Kaffir lime (*Citrus hystrix*) is a plant species commonly found across Indonesia. It is primarily utilised for the extraction of its essential oil, which is known to possess antimicrobial properties (Febrianti and Ariani, 2020). Currently, steam distillation is the standard method for extracting the essential oil from kaffir lime leaves and stems (Astriani et al., 2021). The distillation process yields three products: essential oil, hydrosol, and solid waste consisting largely of residual leaves and stems (Khasanah et al., 2021). While the essential oil yield is modest typically ranging from 1.4% to 1.6%, depending on factors like sun exposure the solid residue, which constitutes the bulk of material after distillation, remains largely underutilized (Budiarto and Sholikin, 2022). Therefore, further research is required to explore the potential of using this solid waste effectively.

One such potential utilisation is composting. Composting is a biological decomposition process whereby microorganisms break down organic matter such as cellulose, hemicellulose, and lignin into humus-like material commonly referred to as compost (Ekawandani and Kusuma, 2019). The residual kaffir lime leaves and stems are rich in organic matter, primarily carbon and nitrogen, making them suitable substrates for composting. Compost serves as a soil conditioner and improves soil fertility (Chaniago and Inriyani, 2019). When applied to soil, it enhances structure, improves water retention and porosity, and thereby reduces reliance on chemical fertilizers (Ho et al., 2022).

Previous research involving the composting of post-distillation biomass includes a study by Salim and Sriharti (2008) titled "The Utilisation of Patchouli Leaf Residue as Compost". That study demonstrated that the physical quality of the resulting compost met the Indonesian National Standard (SNI). However, it utilised an activator, whereas the present study adopts naturally occurring mixed-culture microorganisms to assess the influence of any residual antimicrobial compounds within the kaffir lime leaves and stems post-distillation.

Aeration is particularly important in composting because it ensures an adequate oxygen supply for aerobic microorganisms, which are more efficient at breaking down organic material. It also helps dissipate excess heat and manage moisture levels, creating optimal environmental conditions for microbial activity while preventing anaerobic zones (Bhave and Kulkarni, 2019). Inadequate aeration and thus poor oxygen transfer are a primary driver of odorous gas production during composting (Zhu et al., 2021), whereas maintaining aerobic conditions through proper aeration mitigates unpleasant odors associated with anaerobic decomposition (Elsabbagh et al., 2025). Moreover, effective aeration is essential for reducing methane emissions, as it limits anaerobic decomposition pathways (Nordahl et al., 2023).

Several factors influence the composting process, including the carbon-to-nitrogen (C/N) ratio and oxygen availability (Williams, 2004). An initial C/N ratio that is too high (>30:1) can prolong the decomposition process, while a ratio that is too low may lead to putrefaction. Oxygen levels are associated with the aeration process; in anaerobic composting, oxygen levels are expected to be zero (van der Wurff et al., 2020). Research by Dimawarnita et al. (2023) showed that compost produced under aerated conditions had a lower C/N ratio than compost produced without aeration.

However, limited research has been conducted on the composting of kaffir lime distillation residues, particularly using natural mixed-culture microorganisms without commercial activators. This is important because residual antimicrobial compounds in the distillation waste could potentially affect the composting process. Therefore, the objective of this study was to evaluate the effect of aeration on the composting process of kaffir lime (*Citrus hystrix*) distillation waste by comparing aerobic and anaerobic conditions using natural mixed-culture microorganisms. The study assessed compost quality based on C/N ratio, temperature changes, yield, visual appearance, and organoleptic characteristics, providing insights into its potential as a sustainable soil amendment.

2. MATERIAL AND METHODS

2.1 Equipment

The equipment employed in this study included a thermometer, composting bin, and a moisture balance. Thermometer and moisture balance are used as tools to measure the humidity and temperature of the compost. Composting bin is used as a place where the composting process take place.

2.2 Materials

The materials utilised were water and distilled kaffir lime leaves and stems. The distilled kaffir lime stems is cut into 20 cm long to standardize sizes. While the kaffir lime leaves is not cut.

2.3 Experiment Design

The experiment employed a completely randomized design (CRD) with two treatments: Aerobic composting – composting with aeration using perforated bamboo pipes to provide oxygen, and Anaerobic composting – composting without aeration, with the compost bin fully sealed to prevent air entry.

2.3.1 Composting Bin Preparation

The composters used were rectangular in shape, constructed from wood and bamboo. Each composter was equipped with a removable lid. The dimensions of each unit were 2 m in length, 0.5 m in width, and 0.5 m in height. Each composter was divided into four chambers, each measuring 0.5 m × 0.5 m × 0.5 m.

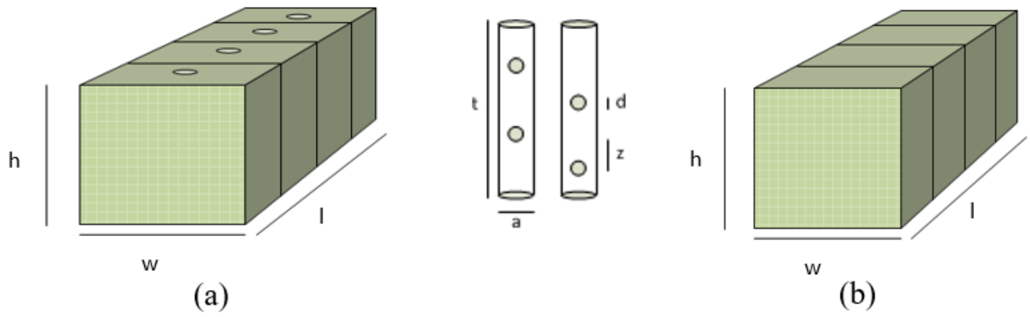

Figure 1. Composting bin a) Aerob, b) Anaerob
h = 0.5 m; w = 0.5 m; l = 2 m; t = 75 cm; d = 10 cm; z = 20 cm; a = ±12 cm

The anaerobic composter had no aeration channels to prevent the intrusion of air from the external environment. Conversely, the aerobic composter featured perforated bamboo pipes for aeration. Each chamber contained one such pipe, placed vertically in the centre. The pipes were perforated with four holes, each 10 cm in diameter, spaced 20 cm apart.

2.3.2 Raw Material Preparation

The post-distillation kaffir lime stems were cut into pieces measuring 10–20 cm. Moisture content was adjusted to achieve a humidity level between 40% and 65%. The ratio of leaves to stems used as raw material was 3:1 by weight.

2.3.3 Composting Process

The composting process began with mixing 15 kg of kaffir lime leaves and 5 kg of stems, resulting in a total of 20 kg of raw material. These were mixed thoroughly and placed into the composters. In the aerobic composter, aeration pipes were inserted at the centre of each chamber.

For the aerobic composting treatment, aeration pipes were inserted vertically at the center of each chamber to facilitate airflow and oxygen supply. The compost temperature, pH, and moisture content were measured daily. The temperature was allowed to rise naturally but maintained below 65°C during the first four days to prevent excessive heat buildup. If the temperature exceeded this threshold, the aerobic composter was opened and the material was turned to release heat and improve aeration. Water was added as needed to maintain moisture levels within the 35–65% range. Additionally, the aerobic compost was turned at least once a week to ensure adequate oxygen distribution and uniform decomposition.

In the anaerobic composting treatment, the bins were fully sealed without aeration pipes to prevent air entry. The compost material was not turned at all throughout the process. Water was only added when the internal temperature exceeded 65°C, helping to regulate heat and maintain microbial activity under oxygen-limited conditions.

For both treatments, water was added at a minimum interval of one week, if needed. The composting process was carried out for a total duration of 8 weeks. Samples for C/N ratio analysis were collected every two weeks, specifically at weeks 0, 2, 4, 6, and 8, by taking representative material from one chamber in each treatment.

2.3.4 Compost Testing

This study was a quantitative experimental study with a descriptive approach. Quantitative data were obtained through direct measurement of compost parameters such as temperature, pH, moisture content, and C/N ratio, while descriptive data were collected through organoleptic and visual assessments. The aim was to quantitatively compare compost quality between two treatments and describe the physical characteristics of the resulting compost. The conclusion was drawn by assessing whether the compost met SNI quality parameters, comparing the final C/N ratio, yield, and organoleptic results between treatments, and identifying which treatment produced higher quality compost and whether aeration significantly influenced the process. Below is the explanation of each parameters:

A. Temperature, pH, and Humidity testing

Measurements of pH and moisture were performed using a soil meter, which was inserted into the central part of the compost pile. These parameters: temperature, pH, and moisture were recorded daily for the duration of the 8 week composting process.

B. C/N ratio testing

C/N ratio analysis was conducted at the Agricultural Technology Assessment Centre (BPTP) in East Java. The carbon content was determined using the dry ashing method at a temperature of up to 600°C. The total nitrogen content of the compost samples was determined using the Kjeldahl method, a standard and widely used technique for measuring nitrogen in organic materials.

C. Visual Testing

According to the standard (Indonesian National Standard, 2004) compost should be dark and soil-like in colour. Visual observations were made by comparing the compost to soil. For baseline comparison, a sample of normal, untreated soil was used as a reference. This soil was collected from the same location where the compost is expected to be applied. The physical appearance, color, and odor of the compost were compared directly to this normal soil during the organoleptic and visual assessments. No statistical tests were applied to the soil sample because it was used solely as a qualitative reference point.

D. Organoleptic Testing

Five kilograms of compost were sieved using a 1-mesh screen (2 mm). The sieved compost was then used for organoleptic testing. According to the standard (Indonesian National Standard, 2004) compost should exhibit a typical earthy or fermented odour. Twenty respondents were engaged to assess the smell by comparing the compost odour to that of local soil from the Department of Chemical Engineering, Universitas Brawijaya.

3. RESULTS AND DISCUSSION

3.1 Temperature Changes during Composting

Throughout the composting process, temperature fluctuations served as indicators of microbial activity, thereby reflecting the different composting phases. The initial phase observed was the mesophilic phase, which lasted less than a day for both aerobic and anaerobic treatments. In aerobic composting, the temperature rose from 36°C to 49°C on the first day, whereas in anaerobic composting, it increased from 33°C to 50°C, indicating the commencement of the thermophilic phase. The thermophilic phase duration differed between treatments: aerobic composting remained in this phase for 3 days (from day 1 to day 3), while the anaerobic process maintained thermophilic conditions for 15 days. The shorter thermophilic phase in aerobic composting is attributed to aeration through periodic turning, which resulted in more heat loss to the surroundings. In contrast, the anaerobic compost retained heat more effectively due to the absence of turning.

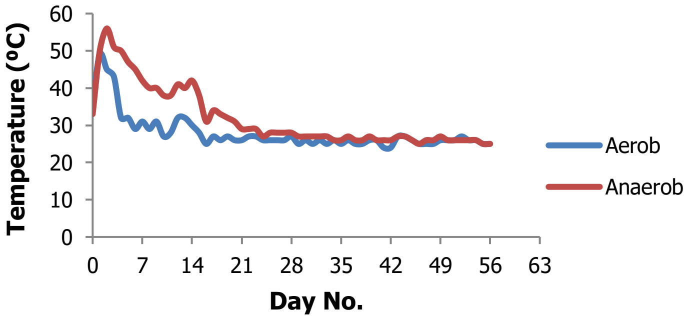

Figure 2. Temperature change in compost

Typically, the thermophilic phase in composting lasts for around 30 days due to sustained microbial activity that rapidly degrades organic matter. However, in this study, the presence of residual antimicrobial compounds in the kaffir lime leaves and stems likely inhibited the growth and activity of beneficial microorganisms. These bioactive compounds, such as essential oils, may have interfered with microbial metabolism, reducing their population and enzymatic activity. As a result, the thermophilic microorganisms were unable to maintain high metabolic rates for a prolonged period, causing an accelerated decline in microbial activity and a premature end to the thermophilic phase. This indicates that the chemical composition of composting materials can significantly influence the duration and stability of the composting process.

Subsequently, the composting process entered the second mesophilic or cooling phase. This phase began on day 4 for the aerobic compost and was characterised by a fluctuating temperature range of 26–32°C. In the anaerobic compost, the second mesophilic phase began on day 16, with temperatures fluctuating between 25–31°C. Although substrate decomposition continued in this phase, it occurred at a slower rate due to reduced substrate availability compared to earlier stages.

The composting process did not achieve the maturation phase. Although ambient temperatures were reached by the final week, the compost still contained undecomposed material. The decline in microbial activity was caused by inadequate composting conditions, including low initial C/N ratios favouring anaerobic decomposition, and excessive mass reduction, which diminished the effectiveness of microbial breakdown.

According to Wang et al. (2024) in small-scale composting systems, the side walls of a composting reactor significantly contribute to heat loss through conduction and convection, due to their high surface area to volume ratio. Forced convection such as that induced by fans or turning accelerates heat dissipation by promoting airflow across surfaces. In contrast, radiative heat loss remains minimal because of the small temperature differential between the compost surface and ambient air.

3.2 C/N ratio

As referenced by (Indonesian National Standardization Agency (2004) the carbon-to-nitrogen (C/N) ratio is a key indicator of compost quality. During the 8-week composting period, C/N ratios were analysed biweekly. The C/N ratio trends for both aerobic and anaerobic treatments are illustrated in Figure 3.

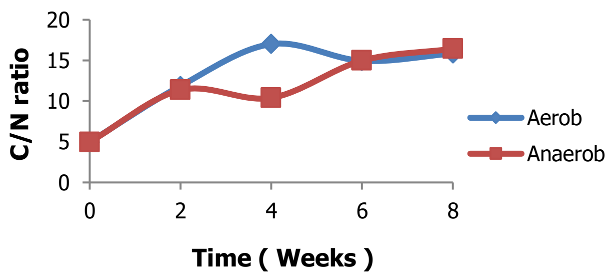

Figure 3. Compost Ratio C/N

The figure reveals that both aerobic and anaerobic composting processes exhibited fluctuating C/N ratios. The raw materials kaffir lime leaves and stems, had a relatively low initial C/N ratio of 4.98:1. According to Al Arni & Elwaheidi (2021) low C/N ratios (<20:1) lead microorganisms to convert a higher proportion of nitrogen into ammonia, particularly under anaerobic conditions. This ammonia generation results in unpleasant odours. As a weak base, ammonia formation is indicated by an increase in compost pH above.

During composting, pH fluctuated, reflecting the nature of the substrate conversion process. Measurements were taken at two points: Point A (the centre of the compost pile) and Point B (approximately 20 cm from the centre). The pH profiles over the 8-week period are shown in Figure 4.

At week 2, both aerobic and anaerobic composts exhibited increased C/N ratios. This indicates that nitrogen was more extensively converted than carbon during early decomposition, resulting in ammonia production and increased pH levels. In aerobic compost at the centre (Point A), pH reached 8, while in anaerobic compost it reached 9.

By week 4, the C/N ratio of aerobic composting increased. This is because at this stage there tends to be only the conversion of nitrogen to ammonia which causes the nitrogen content to decrease. Therefore, the C/N ratio increases. This decrease in nitrogen content is due to the formation of ammonia which will then be released into the air. The formation of ammonia this week is marked by a change in pH reaching 8 at the midpoint of the compost material pile, as shown in Figure 4 (a).

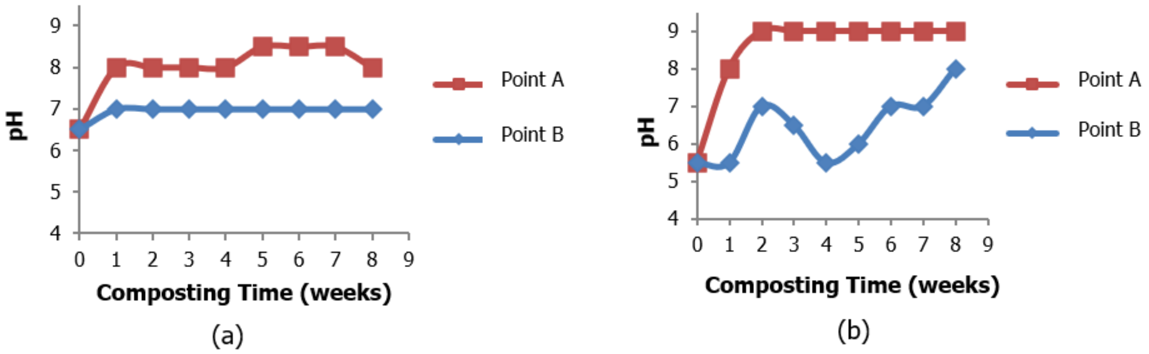

Figure 4. pH change of compost by (a) aerob, (b) anaerob

The decrease in nitrogen levels observed during composting can be attributed to the volatilization of ammonia produced during protein degradation. High temperature and alkaline conditions promote the release of ammonia gas into the atmosphere, resulting in nitrogen loss. Simultaneously, the growth of microorganisms relies on carbon as an energy source, leading to the preferential consumption of simple carbon compounds and the persistence of more complex forms like cellulose and lignin. These processes collectively contribute to an elevated C/N ratio over time, reflecting both nitrogen depletion and the slower breakdown of remaining carbon-rich materials.

In the 4th week of anaerobic composting, there was a decrease in the C/N ratio. Based on the graph in Figure 4 (b), it is known that there is a difference in pH at the midpoint of the compost material pile with the point located at a radius of ± 20 cm from the midpoint. The pH at the midpoint (point A) reaches 9. This indicates the formation of ammonia from the nitrogen conversion process. Ammonia at that point accumulates more than that released into the air, so the pH at the midpoint of the compost material pile is quite high. In addition, it is possible that ammonia gas (NH_3) changes form into NH_4OH because it binds to water. This condition is possible because in anaerobic composting, the water content given is> 65%, so the amount of water in the compost material pile is quite high. Although ammonia is formed at this phase, the existing nitrogen does not decrease, because ammonia is not released into the air.

The pH of anaerobic composting in the 4th week at a point with a radius of ± 20 cm (point B) from the center point (point A) showed an acidic condition of 5.5. This is in accordance with (Rynk et al., 1992) which states that, in anaerobic conditions, decomposed carbon tends to form intermediate compounds in the form of organic acids. There is a difference in the decomposition process at points A and B, where at point A the nitrogen component tends to be decomposed, while at point B the carbon component tends to be decomposed. This is because point B in the composter is closer to the environment, so that its condition is quite influenced by the surrounding environment. Although composting occurs anaerobically, there is still a limited amount of oxygen. Because point B is closer to the environment, the amount of oxygen at point B is greater than at point A, so that carbon decomposition can occur at point B. The organic acids formed can be further decomposed if there is oxygen into methane compounds, so that some of the carbon at point B will be reduced.

Based on the C/N ratio value which decreased to 10.4 then it can be seen that the carbon conversion at this stage is greater than the nitrogen conversion. In the 8th week of composting, the C/N ratio of both aerobic and anaerobic composting experienced a slight increase and tended to be constant. The decrease in nitrogen levels in both composting was the cause of the increase in the C/N ratio. This condition was caused by the decreasing microbial activity. in the composting process. Based on the explanation of the previous sub-chapter, the longer the composting process is carried out, the greater the shrinkage of the compost material mass, so that the environmental influence is also quite large. This results in the failure to achieve the appropriate composting conditions and the decomposition process by microbes slowing down. After composting was carried out for 8 weeks, the final C/N ratio was obtained as follows.

Table 1. C /N ratio of compost at week 8

Composting	Carbon	Nitrogen	C/N ratio
Aerobic	37,60%	2,37%	15.86
Anaerobic	35,64%	2,175%	16.42
SNI Standard	9,8-32%	Min 0,4%	10-20

From Table 1, it is known that the C/N ratio of compost has met the standard (Indonesian National Standard, 2004). This indicates that, chemically, the compost produced in both treatments achieved the minimum requirements for maturity and stability. However, the results indicate that the final compost had an organic carbon content higher than the maximum limit specified by the Indonesian National Standard (SNI 19-7030-2004), which requires carbon levels to range between 9.8% and 32%. This elevated carbon level suggests that the degradation of carbon-rich compounds such as cellulose, hemicellulose, and lignin was incomplete during the composting process. In this study, the raw material distillation waste of kaffir lime leaves and stems contained a substantial amount of structural plant material and essential oils, both of which are highly resistafint to microbial breakdown. Furthermore, the limited aeration and relatively small composting mass may have reduced microbial activity and slowed down decomposition, preventing adequate conversion of organic carbon into more stable forms like humus. As a result, excess carbon remained in the final compost, indicating that the process did not fully achieve maturity. These findings highlight the need for pre-treatment methods, such as size reduction or co-composting with nitrogen-rich substrates, to improve degradation efficiency and bring the carbon content within the required standard.

3.3 Physical Quality of Compost Produced

Based on the results of the organoleptic and visual assessments, 65% of respondents stated that the anaerobic compost possessed an earthy smell. The characteristic smell of soil arises from the combination of organic matter, minerals, and microbial activity (Margolang et al., 2015). In contrast, responses regarding the aerobic compost were more varied, with the highest proportion (38%) indicating that it did not resemble the smell of soil. Thus, the anaerobic compost was found to have a more soil-like odour than its aerobic counterpart.

In terms of visual similarity to soil, 55% of respondents stated that the anaerobic compost had a colour resembling dark brown to black soil. Meanwhile, 35% noted a very strong resemblance, and the remainder responded neutrally. In contrast, responses regarding the colour of aerobic compost were more inconsistent; 45% claimed it did not resemble soil colour, while 35% observed a similarity. These differences are likely due to the varying visual perceptions of each respondent. Nevertheless, it can be concluded that anaerobic compost is more similar in colour to soil compared to aerobic compost.

As for texture, 50% of respondents found the anaerobic compost to resemble the texture of soil, 21% indicated it was very similar, 17% were neutral, and 12% did not perceive any similarity. Although responses on anaerobic compost texture were somewhat inconsistent, more than half perceived it as having a soil-like texture.

For aerobic compost, the organoleptic responses on texture were similarly mixed: 30% stated it resembled soil, 25% stated it did not, 20% were neutral, 20% found it very similar, and the remainder claimed it was not similar at all. Despite this variation, anaerobic compost was deemed more similar in texture to soil, as over 50% of respondents indicated a likeness.

The inconsistent results may have been influenced by the screening process, in which both composts were sieved using a 10-mesh screen (equivalent to 2 mm), leading to similar particle sizes in both compost samples. The screening process also showed that anaerobic compost yielded a higher amount of fine compost. From 5 kg of each compost type, 105 grams of anaerobic compost and 90 grams of aerobic compost were recovered with a maximum size of 2 mm.

Based on Table 2, it is known that the compost yield for both aerobic and anaerobic is very small. This is caused by the composting process that runs very slowly starting in the third week. The very slow composting process is caused by the very large environmental influences.

Table 2. Mass of compost after processing screening process

	Aerobic	Anaerobic
Initial mass (kg)	5	5
Mass after sieving (kg)	0.09	0.105
Yield (%)	1.8	2.1

Despite this, the overall yields were still very low - 1,8% for aerobic and 2,1 for anaerobic composting. This is attributed to the extremely slow composting process, which only began to progress in the third week. One of the main contributing factors was the significant environmental influence due to the small amount of raw material used. Additionally, manual monitoring of composting conditions in the composter further amplified environmental impacts, limiting optimal control over the process. The anaerobic composting process also demonstrated greater instability, resulting in more variable outcomes.

4. CONCLUSIONS

Based on the research findings and discussion, distilled kaffir lime leaves and stems cannot be directly used as composting substrates using natural mixed-culture microorganisms without prior treatment. Although both aerobic and anaerobic composting processes produced compost with C/N ratios that met the Indonesian National Standard (SNI), these results alone are not indicative of successful composting. This is due to the very low compost yields: 1.8% for aerobic composting and 2.1% for anaerobic composting.

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